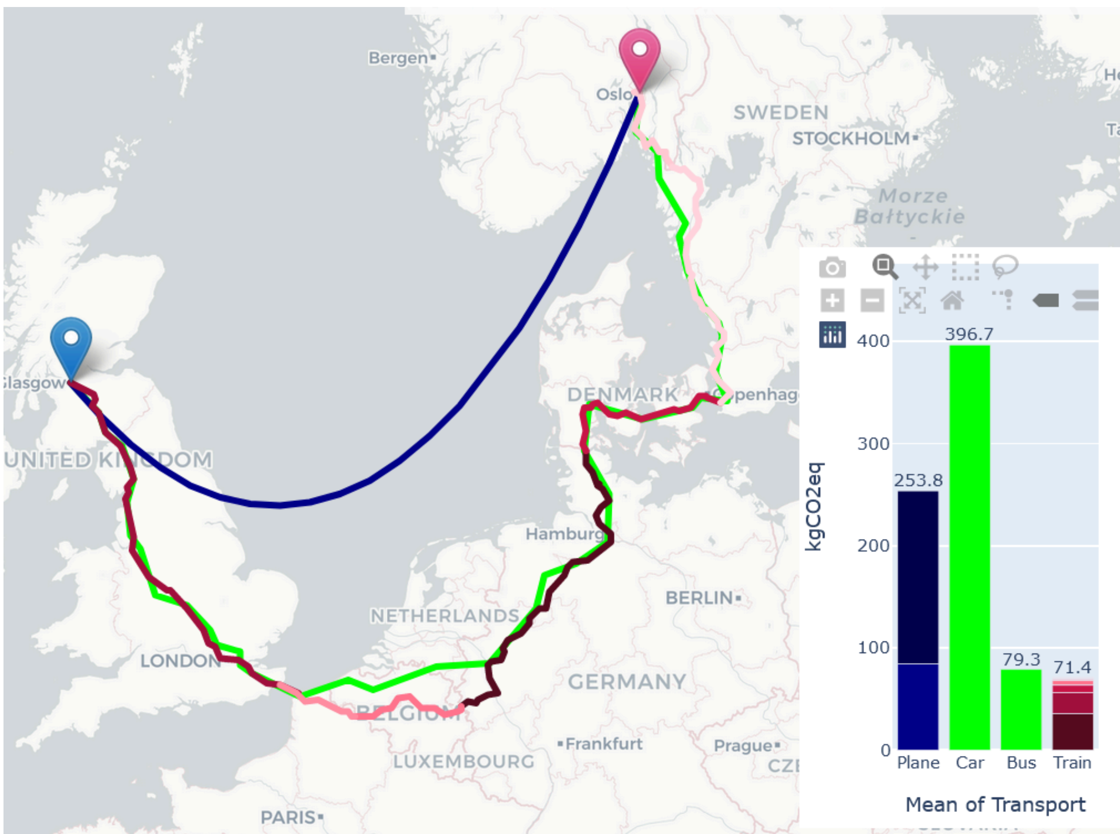
lowtrip

A web interface to compute carbon inventories for different means of travel.



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INTRODUCTION

The work presented here is independent and not-for-profit. This work has been carried out on a voluntary basis and presents no conflict of interest with the authors' work structures or the authors themselves. This work is open-source and all the materials can be found on GitHub[5].

The aim of this web app is to present precise carbon inventories per passenger for each mode of transport and each journey. These results enable users to make informed choices in the context of reducing their greenhouse gas emissions to mitigate climate change. As a reminder, total personal emissions should not exceed $2t\ CO_2eq$ per year in order to achieve carbon neutrality in 2050.

To the best of our knowledge, this is the first open source software that provides this kind of multimodal travel-based information on emissions with such features.

METHODS

The general method to estimate greenhouse gas emissions for one passenger consists of the estimation of an emission factor for a given mean of transport (in CO2eq/p.km) that multiplies the traveled distance.

$$CO2eq_{travel,\, vehicle} \ = \ length_{travel} \times EF_{vehicle}$$

In the following, we describe the methods and hypotheses made in order to compute carbon inventories for each mode of transport. Emission factors are mainly retrieved or updated from the Base Empreinte[6] dataset of ADEME and include upstream and combustion of the traction energy used as well as vehicle construction.

To validate these numbers, a cross validation with other sources and methods is also proposed when possible.

We also integrate a discussion on the contributions or the building of infrastructure and maintenance.

Train

The geometry of the railway for a given trip is provided by the Railway Routing[7] platform that relies on OpenStreetMap (OSM) data[8] . The dataset for railways from OSM can be easily observed on OpenRailwayMap[9].

This geometry is mapped with geospatial data of countries' borders in order to split the geometry in each crossed country. Then, the carbon inventory is computed as such:

$$CO2 \ = \sum_{i \in \{countries\}} length_i \times EF_i$$

With $length_i$ the calculated length of the rail journey in country i such as:

$$\sum_{i \in \{countries\}} length_i = length_{total}$$

and EF_i the emission factor (in gCO2/p.km) of the train for the country i .

Country dependent emission factors for Europe are given by ADEME Base Carbone[6]. Current values are based on the publication « INFRAS-IWW » of International Union of Railways (2004)[10] and reached their end of validity in December 2017. We used the same methodology on the latest report of similar work we were able to find (2011)[11] to compute these emission factors.

For other countries (China, Japan, USA, India & Russia), values were retrieved using the Railway Handbook[12] produced by the International and Environmental Agency and the Union of Railways in 2017. For all other countries, an emission factor of 100 gCO2/p.km is used (order of magnitude corresponding to the highest emission factor proposed by the International Energy Agency[13] for rail).

Such emission factors include upstream and combustion of the traction energy used only. To add the vehicle’s construction contribution, we add the value given by SNCF in its latest report on sustainability[14]: 0.6gCO2/p.km.

Note that these emissions factors are averaged over a country. On specific railways, and mainly due to the nature of the used traction energy (see Figure 1 for instance) and fill rates, these emission factors may vary.

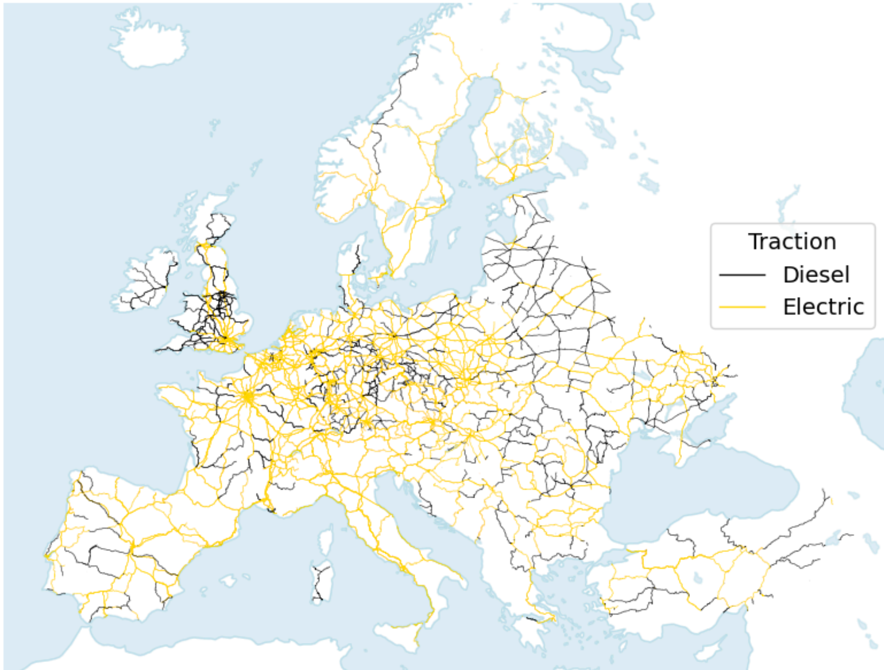


Figure 1 *Electrified and non electrified main railways in Europe from OSM data.*

Cross validation

The emission factor given by UCI for France is 5.4 gCO2/km.pass, which is higher than the 4 gCO2/km.pass suggested in the SNCF latest report but still comparable.

Plane

Plane route was hypothesized to be as the great-circle distance (shortest path between two points on Earth) plus detour and holding phases near the airport. To estimate the coefficient of detour we fitted data from the ATMOSFAIR emissions calculator[15]:

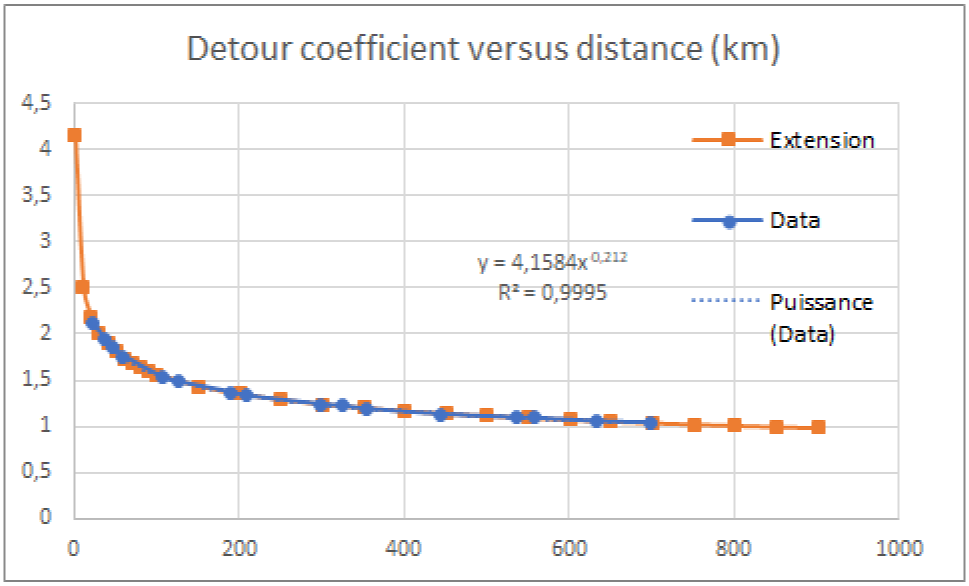


Figure 2. *Detour coefficient for flight path as a function of the great circle distance (shortest path)*

$$distance = \begin{cases} 4{,}1588 \times distance^{-0{,}212}; & distance < 1000km \\ distance; & distance \geq 1000km \end{cases}$$

Holding patterns are taken into account given the order of magnitude given by ATMOSFAIR. Their methodology suggests that it accounts for 1kg of fuel (or 3.81kg of CO2[16]) per passenger. We decided to add this amount of CO2 to the final emissions. We found it an appropriate approach given the low significance on the final emissions.

We took emission factors from ADEME[6] which used data from TARMAAC (Traitements et Analyses des Rejets éMis dans l'Atmosphère par l'Aviation Civile) calculator and the DGAC (Direction Générale de l'Aviation Civile).

Different emission factors are used for CO2 emissions, depending on the trip length:

Distance (km)	**Item**	**Emissions (gCO2/p.km)**	**Associated Consumption (L/p.100km)**
< **1000**	Construction	0.38	-

	Fuel	141.2	4.64
1000 - 3500	Construction	0.36	-
	Fuel	102.4	3.37
> **3500**	Construction	0.26	-
	Fuel	83.0	2.73

Table 1. *Emission factors for planes and associated consumption from ADEME*

Cross-validation

Given that the emission factor for kerozen[16] is 3.04 kgCO2/L, one could retrieve the associated average consumption per passenger during the flight using the emission factors derived from the burning of fuel.

A recent report from the flight company AirFrance[17] indicates that the consumption for its newest planes (7% of the off-Hop! fleet in 2021) ranges between 2.5L/p.100km and 2.6L/p.100km which leads to an improvement of respectively 20% and 25% compared to current planes fuel consumption (respectively 3.25 L/p.100km and 3.33 L/p.100km then). The associated consumption retrieved from ADEME's values (Table 1) are of the same order of magnitude.

non-CO2 effects

To take into account non-CO2 radiative effects that are short-lived components (contrails, NOx emissions and its reactions with O3 and CH4), we apply a multiplication factor to the CO2 emission factor to get a CO2-equivalent emission factor value. ADEME uses a factor 2[6] for conservative purposes as this coefficient was evaluated from the 1999 IPCC report and came with very high uncertainties (200-300%).

Recent scientific studies (Lee et al., 2021)[18] suggests to re-evaluate upwards this number to 3 using an adapted Global Warming Potential (GWP*) metric over 100 years. GWP* addresses the challenges related to comparing short-lived and long-lived forcing components. It is computed using 'flow-based' methods that have been introduced representing both short-lived and long-lived climate forcers explicitly as ‘warming-equivalent’ emissions that have approximately the same impact on the global average surface temperature over multi-decade to century timescales.

These studies also reduced the amount of uncertainty in the non-CO2 terms to +/- 70%. This is partly due to the development of process-based approaches simulating contrail cirrus in recent years. We propose here to apply a coefficient of 3 using GWP* (latest best estimate) with margin errors corresponding to +/- 70%. ATMOSFAIR[15] compared different metrics and similar literature and decided to use the same value.

$$EF_{final} = EF_{fuel} \times (1 + (2 \pm 1.4)) + EF_{Construction}$$

Please note that applying this coefficient on the flight level might be inaccurate in the sense that all flights do not produce the same amount of contrails cirrus: the method we employ here is an average used to account for a global phenomenon.

Car & Bus

The road shortest route is computed via the Open Street Map Routing[19] (OSRM) API. The total length of the journey is then computed and multiplied by an emission factor.

Emission factors for private car and bus coaches were retrieved from ADEME[6] which used the Handbook of Emission Factors for Road Transport (HBEFA) data. It was originally developed on behalf of the environmental protection agencies of Germany, Switzerland and Austria. In the meantime, other countries (Sweden, Norway, France) and the JRC (European Research Centre of the European Commission) are supporting the process.

Type	**Item**	**Emissions (gCO2/km)**
Car	Construction	25.6
	Fuel	192

	Total	**217.6**
Bus	Construction	4.42
	Fuel	25
	Total	**29.42**

Table 2. *Emission factors for car and bus from ADEME*

For private cars, we display emissions associated with different filling rates (1 to 5 passengers) to account for carpooling.

<u>Cross Validation</u>

Emission factors were also computed with the COPERT[20] methodology for the mode "Highway" and a speed of 120km/h. We average values from diesel and petrol cars from 3 different segments with Euro 6 a/b/c standard. Other GES than CO2 were not taken into account as they are too few emitted to significantly change the value of CO2eq. These values do not take into account the construction of the vehicles.

Passenger Cars	Segment	gCO2/km
Petrol	Small	165.5491
	Medium	191.5759
	Large-SUV-Executive	226.5866
Diesel	Small	165.9873
	Medium	165.9873
	Large-SUV-Executive	236.5592
Total		**192.0409**

Table 3. *Emission factors for car at 120 km/h Highway mode from COPERT*

The same approach was applied for standart coaches (<18t) at 90km/h:

$EF_{bus} = 599\ gCO2e/km$

Category	Fuel	Segment	Year 2018 Urban Off Peak	Urban Peak	Rural	Highway	Total
Buses	Diesel	Urban Buses Articulated >18 t	0	0	0	0	0
		Coaches Standard <=18 t	680.7401	680.7401	680.7401	599.0042	660.3061
		Coaches Articulated >18 t	0	0	0	0	0
	Diesel Total		680.7401	680.7401	680.7401	599.0042	660.3061
	Diesel Hybrid	Urban Buses Diesel Hybrid	0	0	0	0	0
	CNG	Urban CNG Buses	0	0	0	0	0
	Biodiesel	Urban Biodiesel Buses	0	0	0	0	0

Figure 3. *Screenshot of emission factors for bus at 90 km/h from COPERT*

Taking into account a share of 60%[21] and a maximum number of passengers equals to 50 we get the following emission factor: $EF_{bus} = 19.7\ gCO2e/p.km$

These values are consistent with the ones retrieved from ADEME (Table 2).

Ferry

Ferry path is considered to be a straight line between departure and arrival and our software does not take into account land presence nor accurate sea routes yet. As a result, the user should be careful while using this mean of transport.

For the emission factor, we retain the order of magnitude determined by the analysis of Maël Thomas-Quillévéré in Future.eco[22]. This value is associated with high uncertainty as it depends greatly on the co-presence of a car and services used onboard.

$EF_{ferry} = 300\ gCO2e/p.km$

Infrastructure

The emission factors discussed above do not account for infrastructure and maintenance. In Figure 4 Carbone4[23] suggests that both construction and infrastructure accounts for very little on planes, while it's important for cars and rail. Knowing from our previous analysis that train's construction accounts for very little, these additional emissions might be attributed mostly to railway infrastructure. For cars, vehicle's construction weighs more in the final result but still infrastructure seems to add significant additional emissions.

Overall, adding infrastructure-related emissions do not greatly change absolute differences in terms of emissions (except for electric cars). As this bar chart comes with no further sources or explanation, further investigations might be needed.

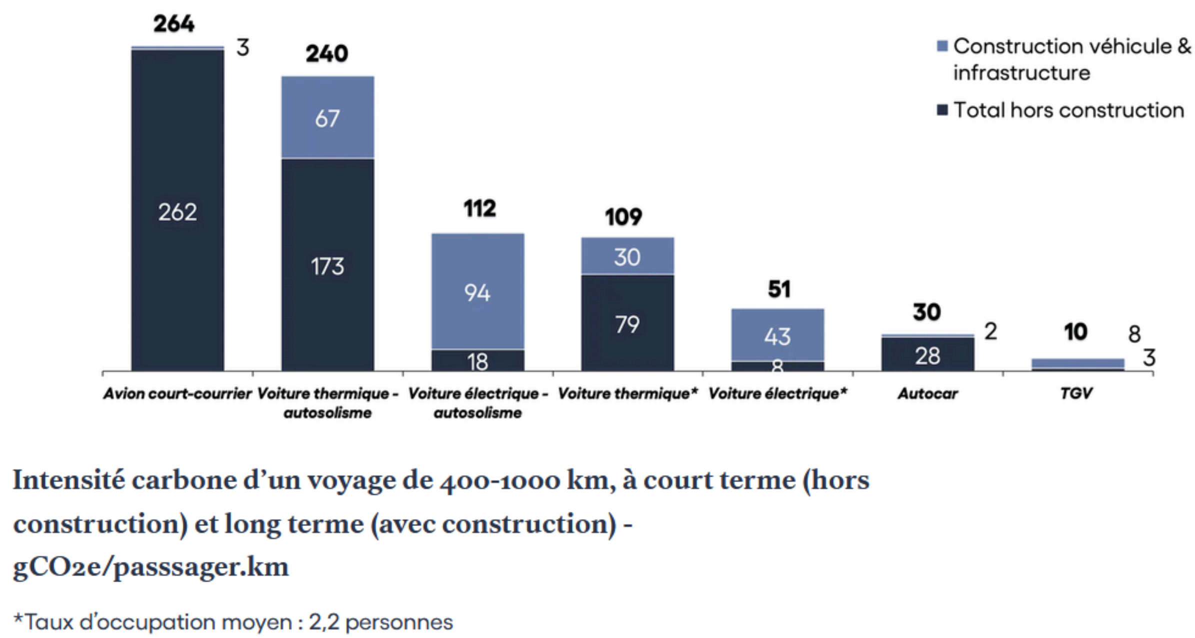
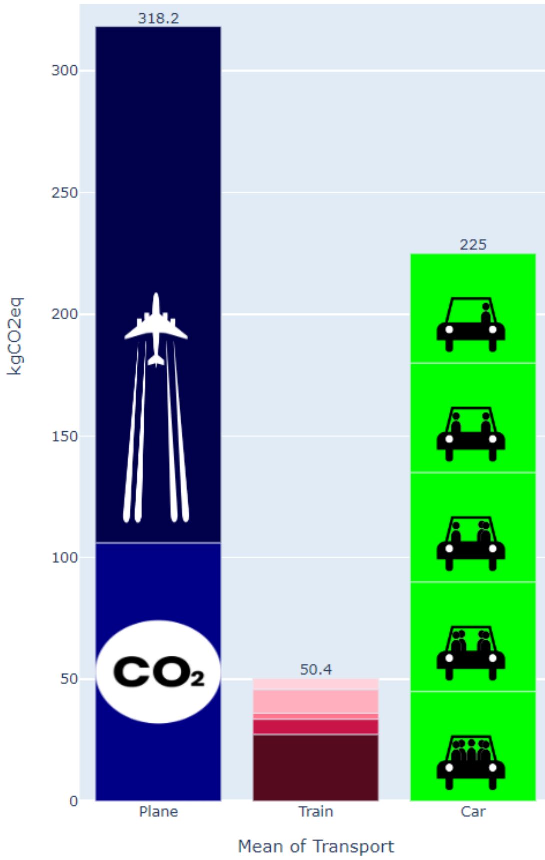


Figure 4 *Emission factors with and without vehicle construction and infrastructure from Carbone4*

RESULTS

show a graph example and explain how to read it



FUTURE DEVELOPMENT IDEAS

All

- Add estimated travel time and price
- Add infrastructure emissions
- Add bike and public transport

Train

- Distinguish emission factors between electrified railways and non-electrified railways
- Distinguish high speed railways and regional railways
- Distinguish different filling rates scenarios

Plane

- Create or use an API to compute only flight routes that exist
- Account for taxiing emissions
- Distinguish between flights that produce contrails and others

Car & Bus

- Distinguish different average vehicle fleets for different countries (currently France)
- Distinguish different emission factors for speed limits depending on the road
- Add electric cars and related emission factors based on the carbon intensity of electricity in each country
- Distinguish different filling rate scenarios for bus

Ferry

- Create or use an API to use existing ferry routes
- Create more options (ex: car or not) to compute a more detailed emission factor

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